A Study of Talking Distance and Related Parameters in Hands-Free Telephony

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This paper outlines the problems of providing satisfactory hands-free operation of the telephone and discusses various methods which can be applied to their solution. Particular attention is given to acoustic environment, proximity talking (as applied to hands-free operation of the telephone) and voice switching. Preference indications were obtained for 18 subjects in 18 different locations for proximity and distant talking without voice switching, and for the same number of subjects and locations for proximity and distant talking with voice switching. In the latter tests, supplementary data were also obtained without voice switching. Regardless of the type of circuitry, the preference decision was considerably affected by the amount of reverberation at the hands-free location; proximity operation was generally favored under conditions of moderate to high reverberation, nonproximity operation under conditions of low reverberation (high room constant). Other factors which affected the preference for hands-free proximity and distant talking are discussed.

I. INTRODUCTION

The hands-free telephone, which provides a convenient way of carrying on associated activities such as turning the pages of reference material, referring to drawings, etc., while the user is talking into a microphone and hearing from a loudspeaker located on his desk, has become an attractive supplement to the handset. This type of operation was first provided as a customer service in the mid-1950's in the form of the 595 telephone set, and soon thereafter in supplementary form as the No. 1A Speakerphone system,[1] neither of which employed voice switching.

The fact that under certain operating conditions hands-free operation can result in singing, in the transmission of reverberation or a barrel-like quality and in excessive noise for the handset listener at the other end of the line has been recognized. The effects of reverberation or liveness of the room and of talking distance have been appreciated. There

has been some speculation concerning the acceptability of reduced talking distance as a remedy for such operational characteristics.[2] More recently, switched gain, in which loss is introduced into the receiving path when the user is talking and into the transmitting path when the user is listening, has been explored as a remedy for some of these effects.[3]

This paper reviews the operational problems of hands-free telephony and gives the results of some experiments in which user reaction to, and acceptance of, various ways of achieving hands-free operation were studied. The tests were carried out in offices in which the "reverberation" was measured in one or more ways. Two different talking distances were provided, one by means of a microphone on an elevated arm about five inches from the lips (proximity talking) and a second by means of a microphone on the desk top about 20 inches from the lips (distant, or nonproximity, talking).

II. OPERATIONAL PROBLEMS OF HANDS-FREE TELEPHONY

To provide hands-free operation of the telephone, amplification must be introduced in both the transmitting (microphone) and receiving (loudspeaker) branches of the circuit. The amount of gain that can be so introduced in a properly installed set, before operational difficulties are encountered, is limited primarily by the acoustic properties of the location and by the hybrid balance afforded by the connecting line and trunk. These operational difficulties may be classified as follows:

(a) sustained feedback, or singing;

(b) enhanced sidetone, or return of the far-end subscriber's voice to him in the form of a reverberant echo;

(c) reduction in the transmitted signal-to-noise ratio and

(d) increased transmission of reverberant energy to the far end of the line.

2.1 *Sustained Feedback, or Singing*

If the loudspeaker of a hands-free set is placed too close to the microphone, or if the loudspeaker volume is turned up too high, the system will sing. The diagram of Fig. 1 indicates this will occur whenever the gain of the transmitting branch of the circuit, G_T, plus the gain in the receiving branch of the circuit, G_R, is greater than the loss of the hybrid coil, L_H, plus the loss of the air path, L_A. The transmitting gain is normally fixed for a given nominal talking distance in order to deliver a level to the central office that is comparable to that delivered by a

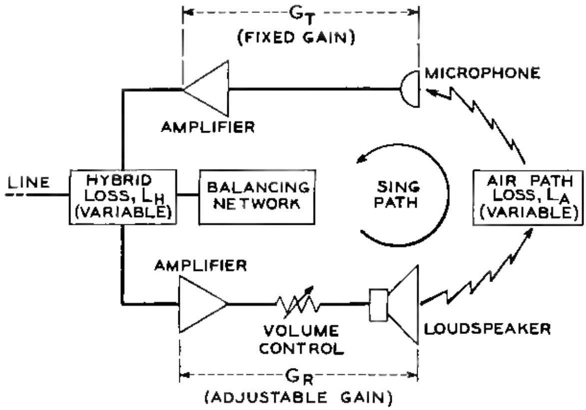

Fig. 1 — Electroacoustic path of signal for singing condition: $(G_R + G_T > L_H + L_A)$.

500-type set on a long loop. The gain in the receiving or loudspeaker branch is adjustable and under control of the hands-free subscriber. Singing will be initiated if this control is advanced too far, as it might be under noisy conditions, or if the incoming speech signals are low, or if the hearing of the hands-free subscriber is impaired.

Singing will also occur if either the hybrid coil loss or the air path loss become sufficiently small. The former depends on how well the impedance of the balancing network matches the impedance of the line. A varistor matching (balancing) network is used in order to provide some compensation based on variations in line resistance. The compensation is designed to be most effective for the medium-to-longer loop where higher gains are needed, rather than for the shorter loop connection where line losses are low.

The air path loss depends upon the distance between the loudspeaker and microphone and upon the relative amounts of sound which reach the microphone directly and by way of reflections from the walls, ceilings and furniture. If these surfaces reflect most of the energy which strikes them, the level at the microphone position falls off much more slowly as the separation is increased than it does when direct energy only is present.

Fig. 2 shows the ratio of the energy density $\bar{\rho}_P$ at various points within an enclosure to the energy density $\bar{\rho}_1$ at a distance of one foot from the same source in free space.[4] The curves are plotted for various values of the room constant R, which is defined by the relationship

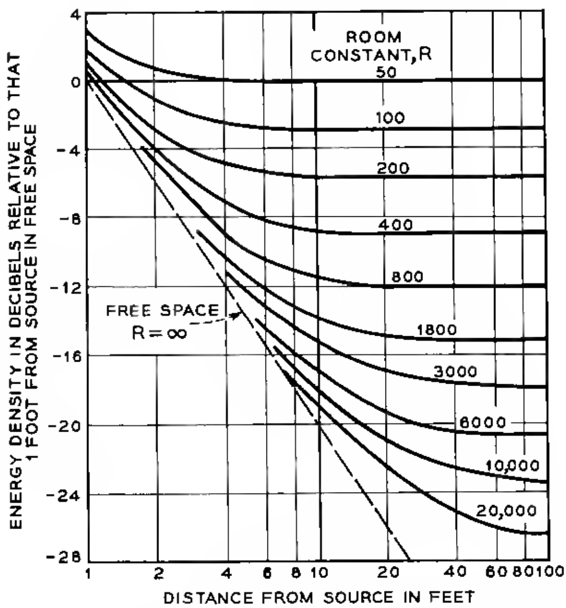

Fig. 2 — Average energy density vs. distance for various values of the room constant R.

$$R = \frac{\bar{\alpha} s}{1 - \bar{\alpha}} \tag{1}$$

$$\doteq \frac{0.05V}{t_{60}(1 - \bar{\alpha})} \tag{2}$$

to a first approximation. Here $\bar{\alpha}$ is the average absorption coefficient of the reflecting surfaces, s is the total area in square feet, V the volume in cubic feet, and t_{60} the reverberation time in seconds.* The value of R is large whenever the ratio of direct to reflected energy is also large (lower curves).

Fig. 2 shows that, in a very reverberant room, increasing the separation of the microphone and loudspeaker does not increase the air path loss very rapidly, although the direct unreflected sound ($R = \infty$) does decrease rapidly with distance, according to the inverse square law.

The next chart, Fig. 3, shows how the permissible (or usable) amplification is reduced as the acoustic environment departs from the ideal

* This is the time required for the sound to die away to one thousandth of its initial pressure, which corresponds to a drop in the sound pressure level of 60 db, following abrupt cessation of the generating source.

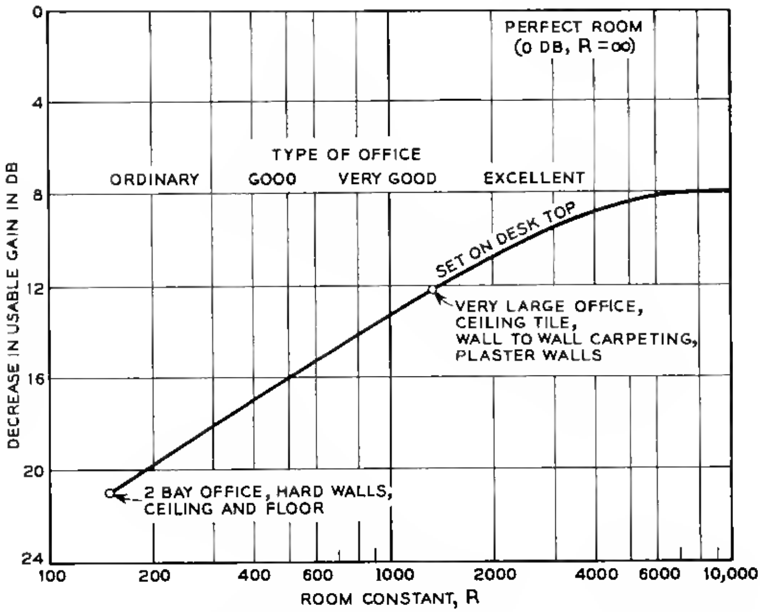

Fig. 3 — Decrease in usable gain as a function of the room constant R.

of free space.[2] Here, the abscissa is expressed in terms of R, the parameter of the previous family of curves. Fig. 3 shows that the introduction of a desk top or similar surface to support the hands-free set reduces the usable gain in an otherwise perfect room by about 8 db. A further loss results when the desk is surrounded by walls, ceiling, floor and office furniture. For an office with a considerable amount of acoustic treatment in the form of drapes, carpeting, acoustically treated ceiling, etc., R values as high as 2000 or more may be achieved. In such cases, the additional loss (beyond 8 db) may be held to a few decibels. In untreated offices, R values of 200 or less may result with an associated total loss in usable gain of 20 db or more. Fig. 3 shows that over the range of "ordinary" to "very good" offices, the room constant R varies from about 150 to 1500 and that about 9 db more gain may be employed in the latter compared to the former location.

2.2 *Enhanced Sidetone, or Far-End Talker-Echo*

When the *handset* subscriber talks into the transmitter, the principal component of the voice signal travels over the line to the party at the

other end, although a part of it appears in the handset receiver as sidetone. When the distant end of a handset call is terminated by hands-free equipment, a second source of receiver sidetone is added: a reverberant echo from the reflecting surfaces of the room in which the hands-free set is located. Objectionable amounts of enhanced sidetone may be fed back to the handset subscriber without the singing condition, previously described, being initiated.

2.3 *Reduced Signal-to-Noise Ratio*

For a talking distance of 5 inches, measurements show that some 13 db insertion gain is required to obtain the same direct-energy speech levels at the input to the line as those delivered by the handset transmitter when the latter is used at a talking distance of half an inch. About 25 db insertion gain is needed for a talking distance of 18 to 21 inches. This amplification not only raises the level of the direct and reverberant speech signals, but also increases the level of the transmitted noise, the net result being a reduction in the transmitted signal-to-noise ratio compared to that obtained with the handset. For transmission from a location of average noise level,* the signal-to-noise ratio would be quite acceptable for a 5-inch talking distance but would be rather noticeable for an 18- to 21-inch talking distance. For a noise ambient above about 60 db, the transmitted noise rapidly becomes very objectionable when a talking distance of 18 to 21 inches is used. For 5-inch proximity operation, this occurs for noise ambients above about 70 db.

Fortunately for the handset user in the case of a 5-inch talking distance, the hands-free user tends to revert to the handset before the noise transmitted to the handset end becomes intolerable; this is not so (because of the larger amplification of the transmitted signal) for an 18- to 21-inch talking distance.

2.4 *Transmitted Reverberation*

It has been recognized that the liveness or reverberant character of a room affects the ratio of direct-to-reflected energy which is transmitted to the far end of the line, and a curve has been given which relates talking distance and the room constant R at which reverberation effects are just below a noticeable level at the handset end of the line.[2] This curve is reproduced in Fig. 4, where it can be seen that R must be above 1500

* As used here, average noise refers to a level of 50 dbA (50 db above a reference acoustic pressure of 0.0002 dyne per cm^2, 40 db weighting). This value was reported by Inglis on the basis of several surveys covering a large number of installations.[5] Individual values, however, may differ from this value by a considerable amount even for similar locations.[6]

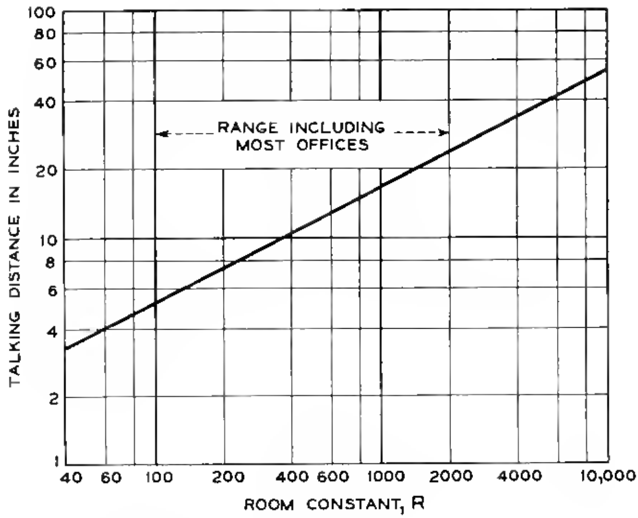

Fig. 4 — Maximum talking distance for no noticeable reverberation at the handset end of the line.

for a talking distance of 21 inches if reverberation effects are to be avoided, but may be as low as 90 for a talking distance of 5 inches. These values of R correspond to offices which are, respectively, well above and well below the average location from the standpoint of reverberation.

The room constant R is one of the parameters of the tests described in this paper. Unfortunately, this could introduce some error in the interpretation of the results. The room constant R is not a complete or completely reliable description of an acoustic environment, and, indeed, we are far from having any completely trustworthy assessment.

In particular, the room constant may fail to assess acoustic conditions of offices in which all of the acoustic treatment is concentrated on one or two surfaces and in which the installation places the microphone in the vicinity of highly reflecting surfaces. The value normally assigned to R on the basis of measurement is the average of several individual measurements except that "any one value that seems to be very inconsistent with the others (say, by a factor of two or more) should be disregarded, since this value probably results from an unusual condition in one section of the room."*

A knowledge of just such an "unusual" condition, however, is necessary if the individual subscriber's evaluation of the various methods of providing hands-free service is to be properly assessed. For this reason,

* From current instructions for making this type of measurement.

an alternate method of rating a subscriber location is of interest. This method is based on the procedure described by Wente[7] in the mid-1930's for measuring the characteristics of sound transmission in rooms. In this procedure, pressure-level excursions are measured as a function of frequency for a fixed separation between a sound source and a microphone pickup. Wente found that the degree of irregularity of the excursions "could vary markedly" at different locations within the same enclosure even though measurements of the reverberation time tended to give about the same value througbout. He also found good correlation between the degree of irregularity and tbe total amount of absorption present.

Wente's work is discussed more fully in the Appendix. Here we will merely illustrate the effect of room reflections in producing irregularities in transmission for a number of conditions to be noted.

Fig. 5(a) shows the response frequency characteristics of a hands-free set as measured in the free-space room at Bell Telephone Laboratories, Murray Hill, New Jersey, at a testing distance of 5 inches. The over-all smoothness of the curve indicates an essential absence of transmitted reverberation.

The response of Fig. 5(b) was obtained at the same testing distance of 5 inches, but in a rather reverberant room having an R value of about 150. This response is of interest since it represents excursions which are just below a noticeable level in the form of reverberant quality at the handset end of the line. Listening tests indicate this occurs whenever the ratio of direct to reflected energy is 10 db.

Fig. 5(c) shows the response obtained at tbe same testing distance of five inches in an intermediate class office having a measured R value of 805. A comparison with the response of Fig. 5(b) indicates tbat under these conditions the amount of transmitted reverberation would go unnoticed at the handset end of the line.

Fig. 5(d) shows the effect of increasing the testing distance to 21 inches at the Fig. 5(c) location. A comparison of Figs. 5(c) and 5(d) is of interest since tbey serve to illustrate the difference in the amount of reverberant content which is transmitted to the line for nominal 5-incb proximity and 21-inch nonproximity use, respectively. At more reverberant locations tbe quality contrast between these two talking distances would tend to be larger. Under improved conditions the difference would become increasingly less noticeable until, under free-space conditions, neither talking distance would result in tbe transmission of reverberant energy.

The response frequency characteristics of Figs. 5(e) and 5(f) are

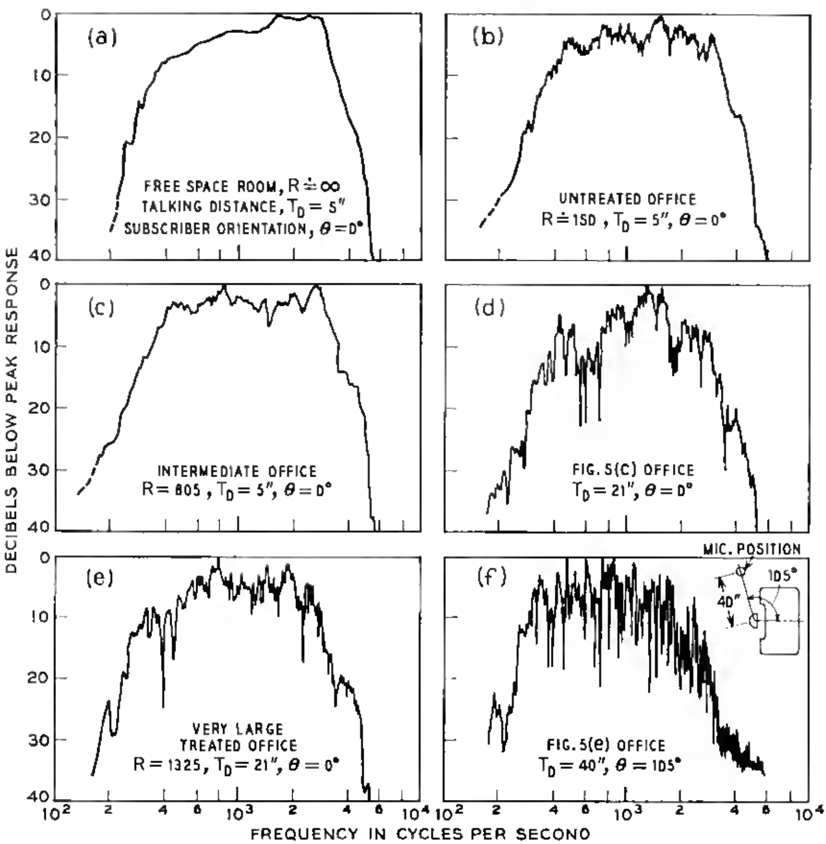

Fig. 5 — Response frequency characteristics of hands-free set for various conditions of operation.

examples of the transmission of excessive amounts of reverberant energy from a rather spacious office (V = 5760 cubic feet) which the large room constant indicates to be very good (R = 1325). Such a room constant should provide freedom from reverberation effects for talking distances up to 19.5 inches. In the present case, however, the set was installed on a side table in a corner of the office near highly reflective hard wall and window surfaces. This materially reduced the beneficial effects of the full ceiling treatment and the wall-to-wall carpeting. Fig. 5(e) shows a response frequency characteristic for a talking distance of 21 inches. Although this distance is only slightly in excess of the 19.5-inch separation noted above, the chart shows a rather noticeable amount or rever-

berant content as indicated by a comparison with Fig. 5(b). Fig. 5(f) shows a transmission measurement which illustrates the combined effect of an excessive talking distance and an unfavorable subscriber orientation, θ. This measurement was made on the assumption the subscriber would remain facing the desk (as indicated by the small inserted sketch), as might be the case if drawings, notes or similar material needed to be referred to during the course of the hands-free connection.

Clearly, room constant does not give an adequate description of the acoustic environment, and, even a "good" room can give poor results if badly used. This should be kept in mind in connection with data on hands-free performance.

III. POSSIBLE SOLUTIONS TO THE PROBLEMS OF HANDS-FREE TELEPHONY

As noted in the previous section, the problems associated with hands-free operation of the telephone are somewhat varied and complex. The situation is further complicated by the fact that the penalties of this type of operation are largely imposed on the handset subscriber at the far end of the line who receives none of the benefits of this type of operation. It is only when such a person reacts unfavorably by way of verbal feedback (or complaint) that the hands-free subscriber becomes aware that some of the operational characteristics, which he may otherwise tend to ignore, may be quite annoying at the handset end of the line.

3.1 *Voice Switching*

In the interval since the introduction of the 595 telephone set and the 1A Speakerphone system, experiments with voice switching as a method of improving hands-free operation of the telephone have been undertaken.* In such systems,[3] variolossers are normally employed in both the transmitting and receiving branches of the circuit in such a way that attenuation is introduced in only one circuit at a time. For one such system, the set is in the receiving condition during the quiescent or normal state. That is, incoming speech signals reach the loudspeaker without being attenuated by the variolosser in the receiving branch of the circuit. Outgoing signals, on the other hand, must switch out the attenuation of the transmitting circuit variolosser before reaching the line. The circuit returns to the quiescent or receiving state when either the hands-free subscriber stops talking or the level of the incoming speech is high enough to override the input from the hands-free microphone.

* The use of voice switching in communication systems is not new. One of its early uses was in connection with transatlantic two-way radio.[8]

An auxiliary rectifier circuit differentiates between loudspeaker output and hands-free speech input to prevent the former from switching itself off.

Voice switching, in which substantial amounts of attenuation are introduced by the variolossers, thus essentially provides two one-way telephone circuits, only one of which is activated at a time. This type of action eliminates two of the operational problems outlined in Section II — enhanced sidetone and sustained feedback of howl — since neither can occur unless both the active and the return paths are conducting at the same time. By this same action, however, a completely free-flowing interchange of conversation is inhibited. In spite of these limitations, the use of this type of circuitry appears promising as a method of controlling enhanced sidetone and sustained feedback, but not of controlling transmitted reverberation or of improving the signal-to-noise ratio.*

3.2 *Proximity Talking*

Since the problems of providing hands-free operation of the telephone are a direct result of increased talking distance, the most direct way of improving transmission is to provide a microphone arrangement which can be used at closer range than the 18 to 21 inches typical for a microphone at desk level. In view of this, the component parts of a 595 telephone set shown in Fig. 6(a) were rearranged into the experimental arrangement of Fig. 6(b). The on-desk elements of the latter consisted of a 500-type telephone set and the combination microphone-loudspeaker arrangement shown at the right. This experimental unit was initially used during a series of non-voice-switched trials at San Francisco.

To initiate a call with the arrangement of Fig. 6(b), the subscriber pulled the supporting arm forward. This rotated the microphone into the talking position shown and closed an ON-OFF switch located within the sphere at the base. Dialing was completed in the usual way.

The call could be transferred to the handset, if desired, by removing this unit from the cradle, as in ordinary use of the telephone. To transfer back to proximity operation, the handset was replaced on the cradle

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* The use of a four-wire transmission line between calling stations also provides a means of eliminating all feedback paths except the round-trip path involving the acoustic coupling between the microphone and loudspeaker elements when two hands-free sets are used in a "back-to-back" connection. The chief disadvantages of this method are primarily those of cost and administration. A directive microphone might also be employed to some advantage for individual use. For conference application, however, directive restriction is not desirable. Also, the improvement from directivity decreases as the liveness increases, and thus it is least effective where most needed.

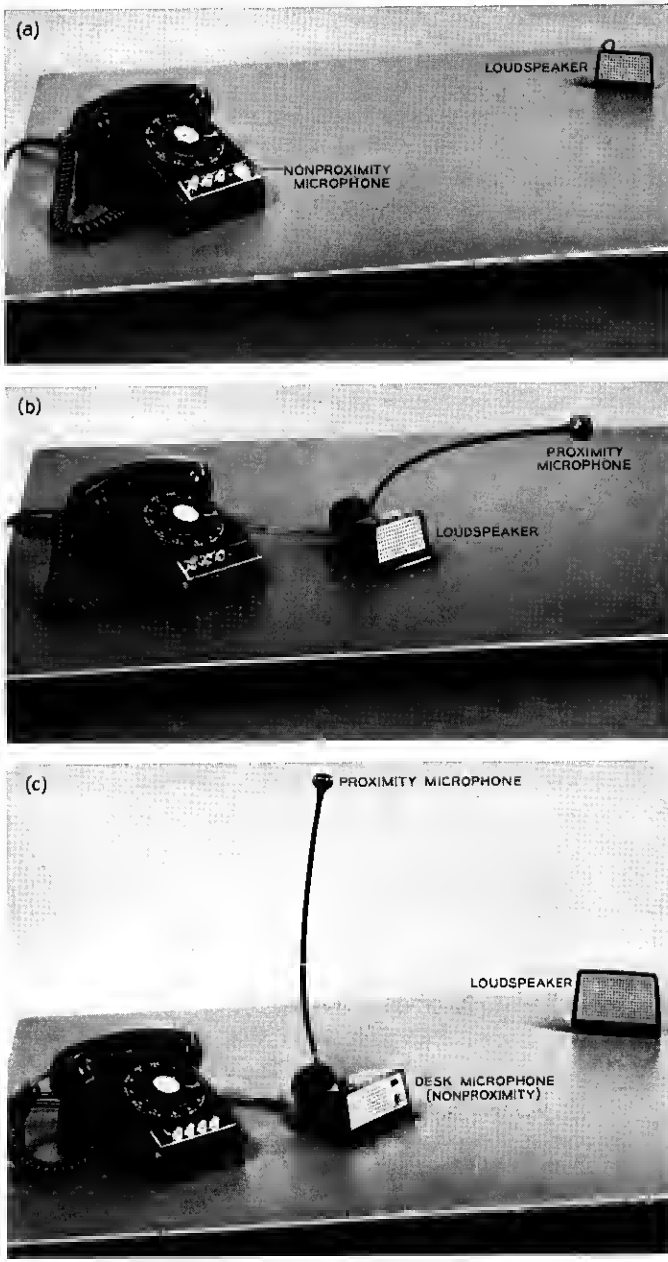

Fig. 6 — Hands-free set arrangements for proximity-nonproximity preference studies: (a) 595 telephone set; (b) proximity-talking microphone assembly; (c) combination proximity and nonproximity voice-switched telephone set.

while the proximity microphone was in the forward position. If it was replaced while the arm was vertical, the call was disconnected.

The location of the loudspeaker unit of Fig. 6(b) on the same base as the microphone had the advantage of directing the subscriber's attention in a common direction. It had the disadvantage of increasing tbe acoustic coupling between these two elements, thus decreasing the air path loss compared to that available with tbe arrangement of Fig. 6(a).

An alternate yet similar method which was used to provide proximity operation in a later experiment is shown by Fig. 6(c). Here a detached loudspeaker unit, similar to but larger than that shown in Fig. 6(a), was used. In this case the combination unit shown toward the center of Fig. 6(c) consisted of an arm-supported proximity microphone and a desk-supported nonproximity microphone as indicated. This arrangement was used during a second series of bands-free trials at Murray Hill office locations — this time in conjunction with the experimental voice-switched circuitry previously described.

Transfer from one microphone to the other was controlled by the position of the microphone arm. In the vertical position shown, the set operated as a nonproximity instrument; in the forward position, as a proximity device.

IV. PREFERENCE INDICATIONS FOR THE PROXIMITY AND NONPROXIMITY FEATURES

4.1 *The Non-Voice-Switched Trials*

This study was conducted in a San Francisco exchange area using 18 regular subscribers on a voluntary basis.* Since the original trial was intended to evaluate the performance of the 595 telephone set only, the installation of the proximity feature followed as a separate trial at stations where the 595 set had been in use for at least a month. Because of business travel and vacation schedules, the proximity sets remained installed at the various locations for a period of about eight weeks. Personal interviews were conducted at the conclusion of both series of tests. These interviews included several questions relating to customer reaction to the sets, their effectiveness under different operating conditions and their general acceptability in providing this type of service.

The subscriber locations at San Francisco varied from an office having a room constant of 399 to three having values above 1500. Eleven and

* The San Francisco trials were conducted under the immediate supervision of C. F. Benner of Bell Telephone Laboratories and D. S. Black of the Pacific Telephone and Telegraph Company.

possibly 12 were below an intermediate value of 1000. The great majority of the test participants were self-employed and/or dealing directly in customer relations — ten attorneys dealing with clients and court procedures, three insurance salesmen, one real estate salesman, one wholesale businessman, one person in the restaurant business and two for whom classifications are not available.

It would be expected that under these conditions proximity operation would find its greatest acceptance at locations where the room constant tended toward the lower end of the scale, and that nonproximity operation would find its greatest acceptance toward the higher end. The actual results, as summarized in Table I, show this to be the case. The preferences noted were obtained in answer to the final question of the interview series: "If a hands-free set similar to the one you have been using for the past few weeks were made available, which arrangement would you choose — that is, this one [Fig. 6(b)] or the set you had previously used [Fig. 6(a)]?" The results of Table I have been tabulated in order of increasing values of the room constant R.

The entries of Table I show that of 13 proximity votes ten came from locations having an R value below 1000, and that of five nonproximity (595) votes four came from locations having a room constant above 1000. Of the exceptions, the classification of one location was not obtained while the deviations of the other three from a rated value of 1000 were rather small. The significance of R = 1000 can be noted by again referring to the relationship of Fig. 4. For such a value, reverberation effects should go unnoticed at the hand-set end of the line for any talking distance which does not exceed 17 inches. As previously noted, this

Table I — Preference Indications for Proximity and Nonproximity Operation Under San Francisco Test Conditions

Subscriber Number	Preference	Room Constant, R	Subscriber Number	Preference	Room Constant, R
1	Prox.	low	10	Prox.	882
2	Prox.	—	11	Prox.	928
3	Prox.	399	12	595	947
4	Prox.	429	13	Prox.	1007
5	Prox.	474	14	Prox.	1061
6	Prox.	500	15	595	1235
7	Prox.	562	16	595	1566
8	Prox.	589	17	595	1633
9	Prox.	810	18	595	2412

assumes that the effective value of R at the position of installation does not differ significantly from the rated value.

4.2 *The Murray Hill Trials*

More recently, a second group of 18 individuals volunteered to participate in a comparison of proximity and nonproximity hands-free equipment — the circuits of both employing the voice-switched circuitry previously described. In addition, tests were also conducted without voice-switching, the two series requiring a combined total of about seven weeks testing time at each location. To insure independent preference judgments, the participants were instructed not to discuss any phase of the tests with other participants whom they knew or might later discover were also taking part in the study. In case contact by telephone with such individuals became necessary, they were requested to use the handset. For all other calls, they were asked to use the hands-free feature as much as reasonably possible.

During the voice-switched phase of the Murray Hill trial, the participants were provided with the combination proximity-nonproximity arrangement of Fig. 6(c). They were instructed to alternate between the two features from one call to the next and to transfer to the other feature during the call in case of comment from the far end of the line. Such a procedure provided for multiple direct comparisons of the two features and tended to eliminate practice effects in the use of generally unfamiliar equipment.* Approximately three weeks of testing time was allocated to this phase of the tests, which questioning indicated to be adequate. In no case did the participant feel that lengthening the test would have made any significant difference in his preference decisions.

The locations at Murray Hill covered an R-value range from 498 to 805 which, on this basis alone, would be expected to favor the selection of the proximity feature.

Columns 3 and 4 of Table II show the preferences voted on the basis of calls of a local nature only. They were obtained in answer to the following question: "Of the two types of hands-free service which you have been using, which would you prefer for your local calls if only one were made available? Allocate 100 points between the two to indicate your margin of preference." A tabulation of the higher of the two values only has been used to indicate both the direction and margin of the preference voted. The summation of the last row shows that of the 18 partici-

* One of the requirements for taking part in the trial was that the participant had made little, and preferably no, previous use of this type of equipment.

TABLE II — PREFERENCE INDICATIONS FOR PROXIMITY AND NONPROXIMITY OPERATION UNDER MURRAY HILL TEST CONDITIONS

Column: 1	2	3	4	5	6	7	8
Participant Number	R	Preference Decisions of Test Participants				Estimated Preference of Far-End Subscriber	
		Local		Long Distance			
		Prox.	Desk	Prox.	Desk	Prox.	Desk
1	498		60	60		75	
2	520	60		60		60	
3	538	75		95		100	
4	556	70		90		70	
5	588		90		60	100	
6	658		75		80	55	
7	663	60		90		70	
8	663	75		75		95	
9	673	60		65		80	
10	700		70	70		60	
11	706	85		100		75	
12	710	70		80		80	
13	710	80		100		80	
14	714	55		70		90	
15	720	65		75		90	
16	740		80		80		60
17	802		60		60	60	
18	805	75		60		65	
Votes for		12	6	14	4	17	1

pants, 12 voted in favor of the proximity feature for local call use compared to 6 votes in favor of the nonproximity or "desk"-type feature.

Columns 5 and 6 show the corresponding preference votes for use of the hands-free set for long distance calls, or calls for which the loop losses or incoming levels were noticeably poorer than those generally encountered on a local call. The summation of the last row shows 14 votes in favor of the proximity feature and four in favor of the nonproximity or desk-type feature under these conditions.

It may be noted that, in the above tests, the highest room constant was 805, and that in the San Francisco trial proximity talking was pre-

ferred by *all* users at locations having a room constant of 928 or less. Why did not all of the Murray Hill participants prefer proximity talking?

This might be attributed to the use of switched gain at Murray Hill. However, when the voice-switched sets were replaced by non-voice-switched equipment during approximately the latter half of the seven-week testing period, three votes were transferred from distant talking to proximity talking and four votes were transferred from proximity talking to distant talking, a net *gain* of one vote for distant talking for the use of non-voice-switched equipment. Since each participant had two votes (one for local calls and one for long distant calls) a transfer of one vote represents a net change of only one half of one full preference decision. During these trials, the proximity and nonproximity features were used during separate successive installation periods as had been the case for the non-voice-switched trials at San Francisco.*

Apparently there must be some explanation other than voice switching to account for the tendency of the participants at Murray Hill to use the distant talking feature under less favorable acoustic conditions. The writer believes that differences in motivation of the participants at the two locations and the increased use of the set for conference calls at Murray Hill largely account for the trend observed.

It has been noted that the participants in the San Francisco trial were chiefly self-employed men dealing directly in customer relations. It seems reasonable to expect that such individuals would be strongly influenced by complaints from the subscriber on the handset end of the line, and we have noted that it is only through such complaints that some of the defects of distant talking become apparent to the user of hands-free equipment.

In the Murray Hill trial, all participants were salaried employees and, as such, might not be expected to have the same amount of interest in achieving as good quality transmission to the far end of the line as would the participants at San Francisco. Thus, they could have had less reason for favoring proximity talking, even though they were aware that reception from the distant talking set was generally less acceptable to the handset subscriber than was reception from the proximity set. When asked: "What do you like best about the proximity feature?" their reply was essentially: "The reception was better at the other end of the line" or "There was less unfavorable comment." When the par-

* It should be noted that, because of changes in work location assignments, two of the 18 participants (Nos. 12 and 13) were unable to take part in this phase of the study. However, since both had previously voted twice for the proximity feature (Columns 3 and 5 of Table II), any change in their vote in the latter series of tests could only have further increased the gain noted above.

ticipants were asked: "What percentage of the subscribers on the other end of the line do you think would prefer that you use the nonproximity feature for your hands-free calls and what percentage the proximity feature?" the entries of columns 7 and 8 of Table II show that, in 17 out of 18 cases, the participants thought that a higher percentage of the far-end subscribers would prefer to be called by way of the proximity feature under the acoustic conditions which existed at the Murray Hill locations. Note, in particular, the ratings of participant No. 5, Table II.

Finally, when the six individuals in the Murray Hill trials who had voted for the distant-talking feature were asked to divide 100 points between the proximity and nonproximity features on the assumption they were now working on a fee or commission basis or were dealing directly in customer relations, all shifted their vote to the proximity feature to provide the 18 to 0 vote shown in columns 3 and 4 of Table III.* The crosses of column 3 correspond to participants whose columns 3 and 5 entries of Table II both show a proximity vote. It thus seems likely that participant motivation toward achieving favorable far-end subscriber reaction to the transmitted signal is a significant factor in the establishment of the preference decision of the hands-free subscriber.

In order to determine what was considered the most attractive features of the two methods of achieving hands-free operation of the telephone, the participants were asked: "What did you like best about the nonproximity feature? What did you like best about the proximity feature?" In answer to the former, the almost universal response was "convenience of use and/or more suited for conference connections." In answer to the latter, the reply, as previously noted, was essentially: "The reception was better at the other end of the line" or "There was less unfavorable comment."

The general absence of a 100 to 0 vote in favor of one or the other hands-free feature suggests that the participant might actually have preferred a set which would provide a choice of using either feature in order to more nearly meet the requirements of each individual call. Columns 5 and 6 of Table III show that, in response to such a question, 13 of the 18 participants indicated that this was so. Presumably each individual was also influenced in his rating by various calling needs.

The effect of the need for conference calls is illustrated by the data of columns 7 and 8. Here, column 7 gives the percentage of conference calls

* Here, one of the advantages of voting by division of points is illustrated. Under altered conditions, a re-evaluation of a similar appraisal is made possible without any implication on the part of the questioner that the participant should reverse his previous vote. For example, any one participant might simply have altered a previous division of points without effecting a reversal.

TABLE III — PREFERENCE INDICATIONS FOR PROXIMITY AND NONPROXIMITY OPERATION UNDER MURRAY HILL TEST CONDITIONS

Column: 1	2	3	4	5	6	7	8
Participant Number	R	Vote With "San Francisco" Motivation		Features Desired By Participants		Estimated Percent of Conference Calls	Votes For Desk Feature From Table II
		Prox.	Desk	Both	1st Choice Only		
1	498	90		75		25	1
2	520	×		60		0	
3	538	×		70		0	
4	556	×		70		5	
5	588	75		70		10	2
6	658	90			100	5	2
7	663	×		60		0	
8	663	×		80		5	
9	673	×		75		0	
10	700	70			60	40	1
11	706	×			85	0	
12	710	×			60	1	
13	710	×		60		0	
14	714	×		80		0	
15	720	×		100		2	
16	740	60		75	100	0	2
17	802	70		65		5	2
18	805	×				15	
Votes for		18	0	13	5	Average: 6.3	

as estimated by the individual participants. In general, those making this type of call showed a greater preference for the nonproximity feature than did those making only individual calls. Column 8 shows that eight of the ten votes for the nonproximity feature were from conference call participants. And, since the estimated average percentage of conference calls at Murray Hill was more than five times as large as the average 1.2 per cent reported at San Francisco, it is likely the greater use of this type of service at Murray Hill was also a factor toward the increased preference for the nonproximity feature at the latter location.

V. OTHER FACTORS AFFECTING THE PREFERENCE DECISION

In addition to the various factors which have been shown to affect the selection of one hands-free feature over the other, there remain the differential effects of such factors as microphone response, physical design and the amount of switched loss employed, which for the present tests was quite large. In terms of microphone response, the output of each unit was equalized to give approximately the same response over a frequency range of about 350 to 3500 cps when used at their respective nominal talking distances. For this reason, no attempt has been made to apply any correction to the preference appraisals on this basis. Nor has any correction been attempted on the basis of physical design, since the tests were limited to but one of several arrangements that might have been chosen to provide the proximity feature.

In connection with the amount of voice-switched loss employed, it should be noted that during the Murray Hill trials no reduction was made in this quantity when the proximity microphone was in use, although the lower gain associated with this type of operation would have permitted such an adjustment. This procedure was followed because the circuit to which the proximity feature had been appended did not lend itself to such an interfeature switchover adjustment. Subsequent testing, however, indicated that such a reduction would have resulted in improved proximity operation.

VI. SUMMARY

As the acoustic environment at the hands-free location departs from the ideal of highly absorbent surrounding surfaces and a low ambient noise level, the basic problems of furnishing this type of service become increasingly more difficult, particularly at talking distances comparable to those used during conference-type connections. The problems of enhanced sidetone and sustained feedback can be adequately controlled by the use of voice-switched circuitry, but not without the introduction of other operational difficulties. An improved form of voice switching on an adjustable basis and with careful attention to transient performance holds promise of reducing these effects to rather acceptable levels. This improved operation, however, still leaves unsolved the remaining problems of reduced signal-to-noise ratio and the reverberant quality of the transmitted signal.

In both of two trials involving proximity and distant talking, the proximity feature was preferred over distant talking. In the San Francisco trial, proximity talking was preferred in all instances in which the

room constant was less than 947. In the Murray Hill trial, the highest room constant was 805, yet distant talking was preferred by 5 out of 18 participants under these conditions.

The use of voice switching in the Murray Hill trial might seem to be an explanation of this difference. However, removal of the voice-switching feature affected the preference for distant talking by an amount not judged to be significant. The fact that the room constant is not a completely adequate measure of acoustic environment might account for some of the disparity. It is the writer's belief, however, that the factors of greatest significance are: First, the participants at Murray Hill as salaried employees were less strongly motivated to please the person with whom they talked than were the participants at San Francisco, who were largely self-employed, and second, there was greater use of the hands-free set for conference calls at Murray Hill. Replies of the Murray Hill participants to questioning are in conformity with the first of these concepts, and the greater preference shown at Murray Hill for the distant-talking feature by conference-call participants is in conformity with the second.

The results at Murray Hill show that a majority of the participants at this location indicated a preference for having both the proximity and distant-talking features rather than either alone.

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APPENDIX

Transmission Quality Based on Frequency Response of Path Between Talker and Microphone

Wente[7] defined the degree of irregularity of the sound pressure level excursions of a response frequency characteristic as the sum of the

pressures of all of the maximum points minus the sum of the pressures of all of the minimum points over the frequency range included, i.e.,

$$\text{D.I.} \equiv \sum_{f_1}^{f_2} p_{\max} - \sum_{f_1}^{f_2} p_{\min} \qquad \text{(in arbitrary units).} \tag{3}$$

Alternate definitions of the degree of irregularity have also been proposed since the appearance of Wente's original paper by Bolt and Roop[9] and by Schroeder,[10] the latter having defined the irregularity in terms of the average excursion $\bar{h}$ of successive fluctuations, i.e.,

$$\bar{h} \equiv \frac{\sum_{f_1}^{f_2} (10 \log_{10} p_{\max}^2 - 10 \log_{10} p_{\min}^2)}{N} \text{ decibels,} \tag{4}$$

where N is the number of pressure peaks ($p_{\max}$) or pressure valleys ($p_{\min}$) between the frequencies f_1 and f_2 over which the summation is taken.

While the exact relation between irregularity, as defined, and the ratio of the direct to reverberant energy at the microphone position is an unsolved problem, measurements of this kind provide a direct means of indicating the effect on signal transmission of such parameters as talking distance, microphone placement and subscriber orientation, which a measurement of the reverberation time t_{60}, or a measurement of the room constant R as outlined in Section 2.4, does not give.

In investigating environmental effects by such a measurement at a hands-free location, a sound source having approximately the directivity of the human mouth and head was driven by a sweep frequency oscillator whose driving mechanism was coupled to an X-Y recorder. The sound output of the source was picked up by the microphone of the hands-free set whose output, in turn, was connected to the signal input of the recorder.* In order to simulate actual conditions of use, the sound source was placed at a position in space corresponding to the location which a subscriber's head would assume during actual use of the set.

When the distance from the source is small for such a measurement, the energy which arrives directly at the microphone position may almost completely override the reflected energy, and the response will be smooth. At large distances, on the other hand, the relative amount of reflected energy will be appreciable. At some frequencies the net reflection will

* In the present case, particularly for very large pressure excursions, the frequency sweep rate was not slow enough to permit steady-state conditions to be fully established at the microphone position. In actual practice, the trace obtained also depends on the writing speed of the recorder, its frequency bandwidth and the degree of irregularity introduced by variations in the sensitivity or efficiency of the test equipment.

be in phase with the direct sound, giving a peak. At other frequencies the net reflection will be out of phase with the direct sound, giving a valley. Thus a measurement made at a large distance in a highly reflective room or at an unfavorable subscriber orientation or microphone position within the room will show large fluctuations corresponding to the transmission of a large amount of reverberant energy.

The effect which changes in the above parameters have on the amount of transmitted reverberation has been illustrated by the various cross comparisons of the response frequency characteristics of Fig. 5 in Section 2.4 of the text.

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